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Control of the Peak Linear Power by Using Two Kinds of Fuel Rods in the AHR

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) is developing an Advanced HANARO research Reactor (AHR) based on the HANARO experiences through its design to operation stages. AHR will be a 20 MW multi purpose research reactor and loaded with the HANARO fuel assemblies of a rod type [1].

AHR has a compact core with a high power density for achieving a high neutron flux that is most important in a research reactor. As the average power is high, the control of the peak linear power is very important. The reference core of the AHR shows an acceptable peak linear power in the fresh core. In the equilibrium core, the peak linear power had been assumed to be low. A recent evaluation shows that the peak linear power in the equilibrium core exceeds the target limit [2]. The evaluation was performed with the HELIOS [3] / VENTURE [4] code system and is suspected to be overestimated when compared with the result by the MCNP [5] code in the fresh core. The modeling and fuel management scheme will be improved. Fundamentally, measures to lower the high peak linear power should be prepared.

HANARO uses two kinds of fuel rods for reducing the peak linear power. It is expected that the same method will work well in the AHR.

This paper introduces measures to control the peak linear power including the adaptation of two kinds of fuel rods and evaluates the peak linear power for the equilibrium core using a Monte Carlo burn-up system.

2. Control of Peak Linear Power

The peak linear power could be reduced by loading more fuel assemblies in the core, but, in so doing, the flux level becomes low. The reference core model will be maintained in this paper.

2.1 Reference Core Model

As the AHR is a multi purpose research reactor, the core configuration is optimized according to its purpose. The flux level should be high both at the core and reflector regions. The AHR provides one irradiation hole at the core region, in which the fast neutron flux can be high. The high thermal neutron flux at the reflector region is obtained by the compact core design. The number of the fuel assemblies is optimized for the reactor power. 14 channels are loaded by the hexagonal fuel assemblies, and four channels are loaded by the circular fuel assemblies, and one channel is devoted to the Central flux Trap (CT). Total 576 fuel rods of a standard type are used in the current design of AHR, which results in a core uranium loading of 51.1 kgU. The core reactivity is controlled by four Control Absorber Rods (CARs) made of hafnium. The number of vertical irradiation holes and horizontal beam tubes at the reflector region will be determined later. The reactivity load of 20 mk in the AHR design is reserved for the facilities. The same facilities as HANARO are arranged at the reflector tank in this paper.

2.2 The Geometry of CT

The AHR has a CT hole for providing a high fast and thermal neutron flux at the center of the core. The geometry of CT has an impact on the linear power of the fuel rods near CT. At first, the geometry of CT was selected as the same as that for HANARO. When CT is not used, a hexagonal dummy assembly made of Al is loaded within a hexagonal flow tube. The fast neutrons generated from the fuel rods are moderated and changed into thermal neutrons rapidly at the CT. The maximum thermal neutron flux level is very high and estimated to be about 5.0E14 n/cm^2/sec. Nevertheless, the peak linear power evaluated by MCNP is not high in the fresh core, but the peak linear power evaluated by the HELIOS/VENTURE code system is high in the fresh and equilibrium core. As the CT hole is filled with water and Al, the evaluation by the diffusion theory code seems to be unreal in principle.

The hexagonal flow tube is replaced with a circular flow tube. The gap between CT and other hexagonal flow tubes is filled with a structure made of zircaloy-4 to prevent an over moderation. The change in shape of CT reduces the linear power to about 5% at the fuel rods near CT.

2.3 Reduced Fuel Rod

HANARO uses two kinds of fuel rods to control the peak linear power. One is the standard fuel rod and the other is a reduced fuel rod. Two fuel rods have different diameters to the fuel meat. The peak linear power within a fuel assembly occurs at the periphery region. If the reduced rods are arranged at the periphery region, the peak linear power reduces. When the reduced rods are applied to the fuel assemblies of the AHR, the peak linear power reduces to about 10%.

2.4 Variable Power Core

When CT is not used, the site is loaded with a circular dummy assembly. If CT is loaded with a circular fuel assembly, the fuel economy would be improved. As this core model is different from the reference core model, all safety parameters should be checked according to this concept. First of all, as the amount of the fuel loading is flexible, the reactor power should be controlled in accordance with the constant fission power or the constant neutron flux. If the constant fission power is chosen, the flux level at the irradiation hole and the neutron detector will be variable. As the constant neutron flux is the constant condition for users, the reactor should be controlled by the constant neutron flux. The reactor power is variable at the state of CT. The limit of the nominal fission power is set to 20 MW. When CT is used, the fission power is to be 19.5 MW. We call this concept as the variable power core. The concept of the variable power core reduces the peak power to 2.5%.

3. Calculation of Peak Linear Power

To reduce the peak linear power, the above mentioned methods were employed. The detailed burn-up calculations were performed using the MCNP/HELIOS system [6], which is a kind of Monte Carlo burn-up system. As the core uranium loading is small when compared to the reference core model and it is difficult to fulfill all the requirements. The requirement of the core excess reactivity at the End of Cycle (EOC) is mitigated from 30 mk to 20 mk. The excess reactivity is reserved for the Xe override and the experimental target loading.

Prior to the detailed core calculation by the MCNP/ HELIOS system, the fast burn-up calculation was performed by using only the HELIOS code, in which the 2-dimenstional full core model was used. The cycle length, the average discharge burn-up of the fuel assemblies, the excess reactivity at EOC, and the amount of the required fuel assemblies are deduced using the reactivity rundown curve, which is calculated by the HELIOS calculation. As the peak linear power would be dependent on the loading pattern, the loading pattern is important, which is selected by intuition at a requirement of the minimal movement of the fuel assemblies in this paper. A highly sophisticated loading pattern could lower the peak linear power. If a loading pattern in the equilibrium core is determined, a fresh core converges to the equilibrium core by repeated core calculations, in which the MCNP/HELIOS system is used for an exact evaluation of the peak linear power. The excess reactivity for the operation of one cycle is obtained by loading three new hexagonal fuel assemblies or two hexagonal fuel assemblies plus two circular fuel assemblies. Fuel assemblies reside in the core during 5 or 6 cycles. It is estimated that the reactor can be operated at 19.5 MW without a refueling for 37 days. The excess reactivity is 22.4 mk. The average discharge burn-up of the fuel assemblies is about 52.1%U-235. The peak linear powers at each cycle are within the target limit.

When CT is loaded with a circular fuel assembly, the core characteristics are evaluated by only using the HELIOS code. It is predicted that the peak linear power would be lower than the above case owing to the lower average linear power. As the fuel loading is increased, the core can operated for 40 days at 20 MW. The excess reactivity at EOC is 23.8 mk. The average discharge burn-up is about 55.7%U-235.

4. Concluding Remarks

It is confirmed that the peak linear power of AHR can be maintained under the target limit in the equilibrium core. The reduced rod has a large effect on the suppression of the peak linear power. To compensate for the economic loss in the fuel management, the concept of a variable power core is introduced.

The peak linear power was controlled by using proven technology through HANARO in principle. From now on, we will adapt some new ideas for which we do not have enough experience, at present.

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